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Domestication potential and marketing of *Canarium indicum* nuts in the Pacific: 1. A literature review

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Abstract *Canarium indicum* is an indigenous tree of the lowland forests of Melanesia (Papua New Guinea, Solomon Islands, Vanuatu) and parts of Indonesia producing edible nuts, commercial timber and some minor products. For thousands of years the nuts have been culturally important and a traditional food. Since the early 1990s there have been a number of projects aimed at the wider commercialization of the species, with mixed success. This review evaluates the biophysical and socio-economic literature and suggests how the domestication and commercialization processes could be taken forwards to improve the livelihoods of rural households in Melanesia. Many of the issues facing the domestication and commercialization of *C. indicum* nuts as an Agroforestry Tree Product (AFTP) are similar to those that will be important for the development of other AFTPs. Thus there are lessons that can be learnt from this species which make it a model for other agroforestry tree species.

Keywords Burseraceae · Non-timber forest products · Agroforestry tree products · Post-harvest processing and value-adding · Commercialization and marketing · Rural livelihoods

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Introduction

Only about 5% of plants have been domesticated and of these only about 6–7% have been domesticated as food crops (Simmonds 1976). A few staple crops (rice, maize, etc.) produce the majority of the world food supply and have been the over-riding focus of agricultural research under the Green Revolution. Nevertheless, it has been estimated that 1.5 billion people (24% of the world population) regularly use products from other species for some of their daily needs (Leakey and Sanchez 1997). In the past these products were collected from natural vegetation, usually forests and woodlands. Many of these

products come from trees (Leakey and Newton 1994) and as a result of deforestation are becoming scarce and unavailable to local communities in both rural and urban areas. In 1994, the World Agroforestry Centre initiated a worldwide programme to domesticate the species identified by local people as their priority for cultivation in agroforestry systems (Leakey and Simons 1998; Leakey et al. 2005). The importance of this initiative, which is based on the needs of poor people, is being increasingly recognized as the issues of poverty, malnutrition, social inequity and local health problems are appreciated as the major issues facing mankind (e.g. Millennium Development Goals). Many crops and traditional foods neglected at the global level are important foods at national or regional levels and contribute considerably to food and nutritional security.

The Pacific island countries of Papua New Guinea, the Solomon Islands and Vanuatu are well endowed with indigenous food species with crop potential (Stevens et al. 1996; Elevitch 2006), especially nut species (e.g. 'Galip', 'Ngali' or 'Nangae' nut (*Canarium indicum*); 'Karuka' (*Pandanus julianattii*), 'Okari nut' (*Terminalia kaernbachii*), 'Pau' or 'Cutnut' (*Barringtonia procera* and *B. edulis*) and 'Aila' (*Inocarpus fagifer*); 'Finschia nut' (*Finschia waterhousiana* Burtt). *C. indicum* has been important in the diet of people in Papua New Guinea for about 6,000 years (Thomson and Evans 2006), with archaeological evidence linking it to man going back 14,000 years (Matthew and Gosden 1997). Canarium nuts are important in traditional society of the Solomon Islands, with the ownership of trees being a measure of an individual's wealth and standing in society, and the nuts are a medium for exchange for land and other forms of traditional money (Pelomo et al. 1996). A number of monographs have been written about *Canarium* species (Griffiths 1993), including *C. indicum* (Thomson and Evans 2001, 2006; Walter and Sam 2002), indicating their importance as indigenous food species and their potential as new tree crops. However, scientific knowledge about these species is limited, although there is considerable traditional or indigenous knowledge about their uses as foods or medicines. This review draws together disparate information about the biological and commercial potential of *C. indicum*, mainly from 'grey' literature. There are many knowledge gaps, so it does not form a comprehensive account of the information needed to cultivate this species.

The *Canarium* genus (Burseraceae) contains approximately 100 species, of which 75 species are found mainly in tropical Asia, and the Pacific (Leenhouts 1959). Eight species in South-east Asia, Australia and the Pacific have edible kernels (Table 1). In Papua New Guinea, *C. indicum* L. is widespread in the lowland forests of East and West New Britain, Bougainville, New Ireland, Manus, Morobe, Madang, East and West Sepik, and Milne Bay provinces (Akus 1996) growing on coastal lowlands up to 700 m (rarely up to 730 m) altitude (Bourke, unpublished). A soft-shelled variety is reported to occur in the Misima Islands (Carlos and Dawes 1990). The wild resource has been estimated at 6 million ha (0.2 trees per ha) in Papua New Guinea, 1.8 million ha (0.5 trees per ha) in the Solomon Islands and 0.3 million ha (1 tree per ha) in Vanuatu (Evans 1996a).

In Papua New Guinea, Solomon Islands and Vanuatu, *C. indicum* is a species of the lowland rainforest, but can be grown up to about 1,000 m in Papua New Guinea. *Canarium* species are typically adapted to high rainfall areas, with rainfall well distributed throughout the year. The optimum rainfall for good growth and fruit production is around 2,000–3,000 mm (Carlos and Dawes 1990), but trees have been reported in areas with precipitation up to 6,000 mm/year (Bourke 1996). *Canarium* species naturally grow well on a wide range of soil types (Carlos and Dawes 1990; Evans 1991a), preferably with well

Table 1 *Canarium* species with edible kernels

Canarium species	Country/region
C. indicum	Papua New Guinea, Solomon Islands, Vanuatu and parts of Indonesia
C. ovatum	Philippines
C. vulgare	Indonesia
C. salomonense	Solomon Islands
C. harveyi	Solomon Islands, Vanuatu, Tonga, Fiji
C. lamii	Papua New Guinea
C. decumanum	Papua New Guinea
C. kaniense	Papua New Guinea

Source: Akus (1996)

drained, deep, friable, sandy loam soil with good organic matter content and a pH of 4.5–6.5, but will tolerate alkalinity up to pH 7.4. However, *Canarium* can be found in poorly drained sites in forest situations (Bourke 1996).

Canarium indicum is a tall, buttressed tree with a straight bole, which can grow up to 40 m in height and 1–1.5 m in diameter (Riley 1922; Carlos and Dawes 1990). It has large imparipinnate leaves up to 30 cm long that form a dense canopy, spreading to 30 m in diameter. *C. indicum* produces large conspicuous serrate stipules up to 60 mm long and 40 mm wide, which are a useful characteristic for field identification. The flowers of *C. indicum* are typically dioecious, but can be hermaphrodite (Chandler 1958). Effective pollination requires the presence of male trees. Fruits are terminal or axially, with up to 30 fruits, generally round in cross section, in a single panicle (Verheiji and Coronel 1992). The fruits (typically 60×30 mm) take 5–8 months to reach maturity when they turn from green to blackish purple (Leenhouts 1959). The fleshy endocarp contains a nut which averages 55×20 mm. Nuts have a 3-celled ovary, but the occurrence of only one fully developed kernel is common (Verheiji and Coronel 1992). Fruiting is typically spread over 3 months with kernels developing late in the maturation process. Fruits usually fall to the ground 2–3 months after maturation (Carlos and Dawes 1990).

Flowering has been reported to commence in young trees after 5–7 years (Thomson and Evans 2006). The seasonality of flowering and fruiting in *C. indicum* is poorly understood. Early observations suggested that flowering occurs in October–December in Papua New Guinea (Leenhouts 1959; Verheiji and Coronel 1992), and January to February, further south in the Solomon Islands (Thomson and Evans 2006). This concurs with the suggestion that flowering in *C. indicum* is controlled by day length (Bourke 1996) and that the fruiting season also varies by latitude, starting in April at 3–4°S and continuing to September at 10°S (Bourke 1996; Bourke et al. 2004). However close to the Equator, where daylength is fairly constant, a few fruiting trees can be seen throughout much of the year. For example, there are reports of fruiting from May to August along the south coast of West New Britain Province and in September to December along the north coast (Mais 1997a), while in East New Britain Province the two fruiting seasons have been reported, the main one in October–November and a lesser one in April–May (Nevenimo, unpublished).

Traditionally, the harvesting of *C. indicum* nuts is of great social importance. Rights to harvest individual trees are traded within and amongst clans (Thomson and Evans 2006). Fruits can either be picked up from the ground or harvested direct from the trees. Nut picking can last for 2–4 months, thus, the area under the tree is typically kept clean so that fallen fruits can be easily collected (Evans 1991a). Harvesting from the tree by breaking off the fruiting branchlets has been found to be beneficial as it encourages renewed growth and flowering.

In Papua New Guinea, the yields of *C. indicum* planted at Lowlands Agricultural Experiment Station of the National Agricultural Research Institute at Keravat in East New Britain indicate that young trees produce 800–1200 fruits per tree per year. In the Solomon Islands, nut yields (10% moisture) were found to vary from 80 to 320 kg per tree, with an average on a healthy tree of at least 100 kg nut-in-shell (=15 kg kernel) per year (Evans 1991a). Consequently, nut yield per hectare has been estimated to be 7.7 tonnes (=1.16 tonnes of kernels per ha per year) from trees >20 year old in a plantation planted at 130 trees per hectare. This assumes that 15% of the trees are male (Maima 1993). Other reports indicate that kernel yields early in the life of plantations at 206–625 trees per ha, can be 0.75 tonnes and that by 10–15 years this can rise to 4–7 tonnes (Thomson and Evans 2006).

Products and uses

Yen (1996) claims that *C. indicum* may be the Melanesian species with the longest relationship with humans. Archaeological evidence of its use in Papua New Guinea, go back 6,000, 9,000, 11–12,000 and 14,000 years in Arawe Islands of West New Britain, Buka, Manus and the Sepik-Ramu areas, respectively (Matthew and Gosden 1997). In the Solomon Islands, *C. indicum* nuts were also

used in trade as a form of currency (Pelomo et al. 1996). Currently, approximately one third of the households in Papua New Guinea grow *C. indicum* (Bourke, M. unpublished), this is almost 100% of the households of the coastal lowlands in the ‘mainland’ and all the island provinces.

The kernels of *C. indicum*, which are eaten raw, dried or roasted, are very nutritious (Evans 1991c) and are highly regarded for their role in traditional food and nutritional security (Leenhouts 1959; Verheiji and Coronel 1992). The nutritional value of kernels is based on their high oil, protein, vitamin and mineral contents (Table 2). In the absence of any widely grown leguminous crops in the Pacific, nuts are a valuable source of vegetable-based protein (McGregor 1999), as well as making a significant contribution to vitamin consumption.

In addition to its use as a medicinal product and cooking, kernel oil is used in cosmetics and skin care products. Kernel oil of *C. indicum* contains about 50% saturated fat (34% palmitic and 13% stearic), 38% monosaturated (oleic) and 14% polyunsaturated (linoleic). The oil could potentially be sold as cooking oil or blended with other oils. Using cool-storage kernel oil can have a shelf life of over 2 years, while at ambient temperatures, estimated shelf life falls to about 6 months.

Table 2 Chemical composition of the *C. indicum* kernels compared to *C. ovatum* nuts

Properties	Galip[a] (*C. indicum*)	Galip[b] (*C. indicum*)	Pili[c] (*C. ovatum*)
Moisture (%)		35.4	35.6–51.4
Oil/fat (%)	74.9	45.9	69.2–76.6
Protein (%)	14.2	8.2	11.5–15.7
Carbohydrates (%)	5.5	0.5	2.59–4.32
Fibre (%)	3.2	10.6	
Total energy (kJ/100 g)	2,705	1,838	2,700
Vitamin A (carotene)	27 μg/100 g		13.5 μg/100 g
Vitamin B_1 (thiamine) (mg/100 g)	0.95	0.13	0.95
Vitamin B_2 (riboflavin) (mg/100 g)	0.12	0.06	0.12
Niacin (mg/100 g)	0.4	1.7	0.4
Calcium (mg/100 g)	119	44	119
Iron (mg/100 g)	3	3.5	2.6
Phosphorus (mg/100 g)			508
Potassium (mg/100 g)		627	489

Source: [a] Evans (1991c), [b] English et al. (1996), [c] Coronel (1996)

Since the kernel is about one sixth of the mass of a *C. indicum* nut, every tonne of kernels is associated with 6 tonnes of shell and 25 kg of testa as by-products (Carlos and Dawes 1990). The testa can be sold as an ingredient of animal foods (Evans 1994a). The shell is hard, non-perishable, has high bulk density (460 kg/m^3) and calorific value (20 MJ/kg) (Evans 1991a). It is ideal for cooking or burning. Also it can be fired in kilns to produce clean, dense and high-grade charcoal fuel, which can be refined to ‘activated carbon’ for pharmaceutical uses. Shells can also be used as bedding for horticultural crops or can be carved into jewelry (Evans 1991a). In Papua New Guinea, the shell is used to make pipes for tobacco smoking. It is clear that the shells are an underutilized resource.

Canarium species are resinous trees. Traditionally in the Pacific, the resin of *Canarium* species has been used for caulking of canoes (Yen 1996), body decoration and burnt to generate light (Akus 1997), medicinal ointments, ulcers and as an antiviral treatment. The commercially valuable “Manila elemi” resin is tapped from *C. luzonicum* in the Philippines for use in medicines and incense (Browne 1955). It is also used in paints and varnishes and it gives toughness and elasticity to products such as plasters, lithographic works and perfumery. *C. indicum* oleoresin contains 82% resin and 10% essential oil, the latter is 34% anethole with some terpenes (Evans 1991a).

Traditionally *Canarium* have been used for making canoes and boat making (Akus 1997), firewood and light construction (Cook et al. 1989). In addition, the wood is important for tools, crafts and fuelwood. Large trees of *Canarium* species are commercially important sources of high quality timber in Papua New Guinea (Eddowes 1977), and are especially prized in parts of the Solomon Islands (Makira and Malaita) as a source of cash income. *Canarium* species are often a common timber species in lowland forests in Papua New Guinea. For example, in the 1970s,

Canarium species were the 5th most prevalent timber species in the Vanimo timber area West Sepik Province, and accounted for 2.6% of the timber by volume (Anon 1976). In terms of timber production, the tree is capable of rapid growth, with annual increments in early years of 2.8 m in height and 3 cm DBH (Thomson and Evans 2006).

The timber is fine-textured, a pink-brown colour, medium density (430–560 kg/m^3), a strength class of S5 but is non-durable. Some trees have a decorative wood with veneer potential. These timbers are suitable for: general construction, mouldings, interior finish, veneers, boxes, utility furniture, flooring, lining, joinery, doors and window frames, cabinet work and chip board, but is not suitable for exterior uses unless treated with preservatives (Eddowes 1977). The logs are usually free of natural defects, not difficult to saw and shrinkage is low (Browne 1955). Vigus (1997) describes the wood of *C. indicum*, which is marketed as 'Red Canarium', as being very desirable for furniture making and a high value wood (US\$135/m^3 in November 1996). A 27–30 year old *C. indicum* tree can produce a 3 m^3 log for export or 2 m^3 of sawn timber (Vigus 1997). The usefulness and value of *Canarium* wood is a major cause of genetic erosion in the species. Significant areas of forest containing *Canarium* have and are being commercially logged in Papua New Guinea. A recent study by NARI at Keravat showed that out of 45 superior nut producing *C. indicum* trees identified in villages in 1990, only 25 (55%) remained in 2003. The others had been felled by local people for timber and to clear the land for other domestic and agricultural purposes arising from population growth. This serious depletion of the resource is having an impact on the supply of nuts.

In the Solomon Islands, small plantations were established between 1979 and 1985 at Poitete, Munda, Arara and 2.5 ha at Kolombangara (Chaplin 1988), with timber growth and nut yield data collected for the first 10 years (Chaplin and Poa 1988; Chaplin 1988). By year 10, basal area was about 25 m^2/ha and DBH about 22 cm.

Canarium species have various medicinal uses (Akus 1997), but they are not well documented. However, a patent was recently issued for the use of *C. indicum* kernel oil for the prevention and treatment of arthritis (Sanderson and Sherman 2004). There is some evidence of this being a traditional use of kernel oil (Davis 2004) and this has led to vigourous discussion about the protection of traditional knowledge. In addition, Powell (1976) has reported that the masticated bark of *C. indicum* is used to treat burns. In the Solomon Islands, a preparation from the bark is used to treat chest pains.

In some parts of Papua New Guinea, the *C. indicum* tree itself plays a significant part their culture. For instance, the initiation of male child (main feasting period) of the Nakanai people in West New Britain Province, coincides with the fruiting season, various stages of fruit maturity and fruit fall signals the different stages of the ceremony (Kua 1997). Trees are also important as commemorative and boundary markers (Hviding and Bayliss-Smith 2000). In the Solomon Islands, kernels are an ingredient of traditional puddings made from cassava, yams and taro, as well as mixed with vegetables such as 'slippery cabbage' (Abelmoschus [*Hibiscus*] *manihot*) and many others (Chaplin 1988).

Domestication

The domestication of this species began a long time ago, when local inhabitants started protecting naturally regenerating seedlings. Such trees have the full range of tree-to-tree variation, and farmers will often cut down those trees, which have undesirable traits. In this way local varieties have been developed through selection of trees on the basis of their kernel size and taste, thin pericarp and oil content (Thomson and Evans 2006). Consequently, the species is now most commonly found in agricultural landscapes and thus the products now conform to the definition of Agroforestry Tree Products (AFTPs) rather than that of Non-Timber Forest Products (Simons and Leakey 2004). There is also some evidence to suggest that farmers have gathering wild fruits and planting the seeds of the biggest and best around their dwellings, as well as transplanting wildings, so further instituting the farmers' pathway to domestication (Leakey and Simons 1998).

More formal work to domesticate *C. indicum* is relatively recent, starting in the 1970s at the Lowlands Agricultural Experiment Station (LAES) of the National Agricultural Research Institute (NARI) at Keravat (Akus 1996) and in Solomon Islands in 1980s (Chaplin and Poa 1988). Two field surveys to identify superior *C. indicum* trees were undertaken between 1990 and 1995 by LAES in two Provinces: East and West New Britain. Both surveys sought to identify high yielding trees in farmers' fields in the Gazelle Peninsula (Akus et al. 1996) and were focussed on the domestication potential of the species. In the first survey, nut samples were collected from 45 trees located in 9 different villages in the Gazelle Peninsular of East New Britain. The nut samples ranged from 13 to 220 nuts/tree and illustrated the very considerable tree-to-tree variation in nut characteristics. Mean kernel mass ranged from 1.38 to 3.65 g, with kernel:nut ratios ranging from 0.14 to 0.26 (Nevenimo and Moxon, unpublished). This range of kernel weights is comparable with data from Evans (1996a), indicating mean kernel mass of 1.0–4.0 g. The second survey was conducted by LAES staff in West New Britain Province with funding and assistance from Kandrian Gloucester Integrated Development Project (KGIDP) to evaluate the potential for domestication. Nut and kernel characters were similar to those of East New Britain, but only varied in kernel:nut ratios from 0.14 to 0.18, with the best coming from Bariai area in Gloucester.

Equivalent kernel data for *C. salomonense* and. *C. harveyi* are 0.5–1.5 g and 2–6 g respectively (Evans 1996a), while *C. ovatum* kernels are 0.74–5.13 g (Coronel 1996). *Canarium* nuts vary considerably in shape, size, number of locules filled by a kernel and in shell thickness. Detailed observations of the variability in *C. indicium*, *C. harveyi* and *C. ovatum* have been made, recorded and used to identify which traits are desirable (Evans 1991b, 1999; Coronel 1996). It is not clear from the literature how much this variation is the normal tree-to-tree (phenotypic) variation, and how much is within-tree variation due to environmental factors, such as pollination success (cf. Leakey 2005). It has been widely recognized that kernel size (kernel:nut ratio) is one of the most important criteria for selection, together with ease of kernel extraction, in order to reduce the costs of processing and maximise the gross margins (McGregor 1999). The phenotypic variation in *C. indicum* suggests that there are good possibilities for selecting trees in the Gazelle producing considerably bigger than average kernels. In addition, trees with thin shells have been reported, indicating that there is potential to make the task of nut cracking less arduous (Thomson and Evans 2006).

Conclusions from these surveys were that there is considerable potential to build on the start to domestication made by farmers. However, there is a need to educate people on the economic value of *C. indicum* nuts as a new crop and to discourage the logging and cutting of trees for timber. In addition, research is needed on the biology of the species and on potential production systems. This research should include trees in the Bariai and Gloucester areas to identify superior *C. indicum* nut trees and the development of a national germplasm collection.

There have been similar detailed surveys done in the Solomon Islands, which have included *C. harveyi*, and *C. salomonense* as well as *C. indicum* (Evans 1999). As part of this initiative, 74 *Canarium* specimens had been identified prior to 1992 and planted out in a number of field sites and the Department of Forestry was evaluating the potential of *Canarium* species as a plantation tree crop. However, little progress has been made in recent years. Additional studies were done in Samoa (Carlos and Dawes 1990), and Vanuatu, with many 'folk varieties' being recorded in the latter (Walter and Sam 1996).

Currently, *C. indicum* nut is mainly propagated by seed (Evans 1991a). Seeds take 4–7 weeks to germinate (Chandler 1958), although germination can take up to 17 weeks (Evans 1991a). Best germination rates are achieved when seeds are depulped by removal of the mesocarp and planted soon after harvesting and placed 10 mm deep in light soils (sand + peat or topsoil). Seed germination is greatly enhanced if they are pre-soaked in fresh water for at least 24 h, but, other treatments like scarification, cracking or shell removal were not found to promote germination. The loss of germination during even short-term storage means that the seeds can be classified as

recalcitrant (Evans 1991a). However, depulped seeds can be stored for periods of up to 6 months in a cool, dry place (Evans 1991a).

Trials on the vegetative propagation were conducted in Papua New Guinea between 1990 and 1992, using a range of grafting and budding techniques, but with very poor success rates (Akus 1996; Nevenimo 1993). Tip veneer and side grafting under humidity house conditions were the most successful and 10% plant survival was achieved after 14 weeks. Grafting success in *C. indicum* has also been very poor in the Solomon Islands. Side grafting has had some success on young trees and when top working on 2–3 year old trees (Nonkas and Pasing 1997).

Studies at the Papua New Guinea Forest Research Institute on techniques to rooting stem cuttings of *C. indicum* have also been relatively unsuccessful, with <10% rooting (Gunn et al. 2004). In contrast, studies to develop domestication strategies and techniques for other indigenous nuts *Barringtonia procera* and *Inocarpus fagifer* using marcotting (air layering) and leafy stem cuttings to develop cultivars have been very successful (100% in 3–4 weeks) in the Solomon Islands (Pauku 2004, 2005). Further research is needed as an understanding of the factors determining the success of propagating tropical trees by the rooting of stem cuttings has been greatly improved over the last 30 years (Leakey 2004).

C. indicum trees are an important part of traditional agroforestry systems in the Pacific (Henderson and Hancock 1988) and agroforests are likely to be the dominant farming system in the future. Evans (1991a) has recommended planting *C. indicum* under coconuts and in Vanuatu an economic study of different production models has found that a one hectare orchard, selling nuts to a middleman, has the best returns to land (McGregor 1999).

A good site for *Canarium* cultivation should be fertile, sloping and well protected from the wind, by avoidance of exposed sites, such as ridge tops, and the planting of windbreaks. Only minimal tillage is required after site preparation in secondary forest. This involves the slashing of small trees and shrubs, the felling of large trees and the later burning of dried residues (Carlos and Dawes 1990). When planting, an initial spacing of 10×10 m is recommended for nut production as *Canarium* trees grow very tall and form a large canopy (Carlos and Dawes 1990). This will give a plant density of 100 trees per hectare. Alternatively, for an additional final timber crop with a 6 m butt log, they can be planted at 9–10 m between rows, but 2 m within rows (500–555 stems per ha) and thinned down to 100–150 stems per ha within 6 years (Thomson and Evans 2006). It is important to remember that *C. indicum* is a dioecious species, and therefore it is essential to have some male trees in any planting. A male:female ratio of 1:25 has been recommended (Evans 1991a) and if pollination is inadequate due to isolation, bee keeping is recommended (Chaplin et al. 1988). Best practice is considered to involve planting, at the start of the wet season, of hardened-off seedlings, 3–6 months old, into a hole of $300 \times 300 \times 600$ mm deep, filled with top soil (Evans 1991a). Palm frond shade for the initial 1–4 weeks promotes seedling establishment (Carlos and Dawes 1990).

Weeding is essential during the early stages of seedling growth and should be done once a month. Additionally, the establishment of a ground cover of low growing plants between the rows can reduce costs and also protect soil from exposure and erosion (Carlos and Dawes 1990). This ground cover can be regularly slashed or mown to minimize competition with the trees. Fertilizer applications of 360 g urea (N), 150 g super phosphate (P) and 240 g muriate of potash (K) per tree per year is recommended for the first 10 years (Carlos and Dawes 1990). After this, the rate per tree should be increased proportionally to the size of the tree and applied as several applications evenly distributed throughout the year. No specific pests or diseases have yet been identified for *C. indicum* (Evans 1991a). As the trees grow, crown pruning will promote crown development and promotes flowering (Evans 1991a).

Since the 1980s a few *C. indicum* plantations have been established as monocultures, for timber production or for nuts (Chaplin 1988). For example, a timber stand of 2.5 ha was established in the Solomon Islands on Kolombangara Island in 1984, and others with 5 seedlings of 50 superior morphotypes at Agricultural Research Field Stations

in Malaita and Temotu, as well as some duplicates at Dodo Creek near Honiara (Evans 1999). In Papua New Guinea, plantations have also been established on Ulatawa Estate in the Kokopo area of East New Britain for their nuts (Evans 1994a). This plantation was established in 1991 with 3500 seedlings planted on 50-ha, but it was sold in 1996. At about the same time, Vimy and Vunatung plantations, also in East New Britain, have interplanted cocoa and coconut with over 3,700 *C. indicum* trees.

Interplanting *C. indicum* trees as agroforestry systems within other farming or cropping systems is probably a more sustainable approach to nut production, and one which is more appropriate to smallholder farmers (Chaplin 1988). In this approach, widely spaced *Canarium* trees can be interplanted with commodity crops like cocoa and coconuts, and bananas, as well as with other traditionally important indigenous species such as *Barringtonia* spp., *Pometia pinnata*, *Inocarpus fagifer*, *Terminalia kaernbachii* (Pauku 2006a/b). They are also planted to demarcate land boundaries, provide shade to cocoa and coffee, support economic climbing species and to provide environmental services like soil conservation and windbreaks. Under the Improved Temotu Traditional Agriculture (ITTA) system in the Santa Cruz islands of the Solomon Islands (Bonie 1993), *C. indicum* is one of four sub-line crop species out of fourteen tree crop species grown with ten other food crops, in a complex agroforestry design based around a series of 10 × 10 m squares.

Post-harvest handling and processing

Post-harvest handling and processing techniques for *Canarium* nuts and kernels have been the focus of a number of projects aimed at promoting the marketing of *C. indicum* nuts in Papua New Guinea, the Solomon Islands and the Philippines (Evans 1991c; Maima 1996; Evans 1994a; Srinivasan 1994; Brown 1996; Coronel 1996; Mais 1997b). To produce good quality, marketable kernels from harvested nuts, involves a series of processes to ensure quality and enhanced storage life (Table 3). In the traditional domestic trade, the process stops when the kernel is removed from the testa and either eaten, marketed fresh or prepared with other food. In the Solomon Islands and Vanuatu, kernels are also traditionally dry roasted in stone ovens. The results from these projects suggested that commercial processing and marketing were economically viability, and that there was good marketing potential for roasted nuts both locally and overseas (Srinivasan 1995).

The ease with which flesh is removed from the nut depends on the age of the fruit and on genetic variability (Evans 1991b). The fleshy mesocarp of the fruit is best removed as soon as possible after harvest. It can be done by bruising the fruits with objects like a stone (Carlos and Dawes 1990), dipping the fruits in boiling water for several minutes or by leaving fruits to ferment in bags for 2–3 days after soaking them in water, especially sea water (Evans 1991c). In the latter, the rotting mass is removed either by washing with water or by drying and separating it from the nut. Alternatively, fruits can be put into baskets and placed in the sea until the nuts are clean. These retting techniques are preferred as they minimize the spoilage and are not labour intensive (Mais 1997b). During the soaking process, floating nuts should be removed.

Traditionally, clean nuts are dried in the sun or over a kitchen fire (Evans 1991c). However,

Table 3 The scheme for processing *Canarium* nuts developed by the Food Preservation and Processing Unit of the University of Technology, Lae, Papua New Guinea (after Maima 1996)

Nuts → Grading and buying → Storage → Cracking → Blanching and testa removal
↓
Packing ← Cooling ← Roasting 135°C for 55 mins ← Dehydration 55°C for 8 hours ← Kernel

now Copra Driers or the improved Los Banõs Coconut Dryers (Carlos and Dawes 1990; Evans 1991c) can be used. When the kernels are completely dry in the shell they usually rattle when shaken. For good storage, the moisture content of the kernel should be 1.5% (Evans 1994a). Then when the shell is broken, a clean white-coloured kernel is revealed in its testa. Dried nuts are generally used domestically or sold on local market and roadside stalls (Evans 1994a). When traded commercially, they are packed into 25 kg bags and transported to buying points or to a processing factory (Carlos and Dawes 1990). The quality of dried nuts is determined by kernel to nut ratio (K:N) and graded accordingly (Table 4). *C. indicum* typically has a ratio ranging from 0.10 to 0.27 (Evans 1991a). Similar grading schemes are used in the Solomon Islands and in Vanuatu when nuts are bought from growers (Evans 1994a).

Kernels that have been removed from their shells have a short shelf-life, consequently, it is best to store dried nuts (kernels in shell). The quality of stored nuts will depend on moisture content, maturity of nuts at harvest and the conditions of storage. Fully ripe nuts store better than unripe nuts, having lower percentage of discoloured kernels (Mais 1997b). Typically, kernels are extracted by manually cracking the shells using a stone or hammer (Carlos and Dawes 1990). Care has to be taken not to damage the kernel. In Papua New Guinea, the output per hour of traditional hand cracking has been reported to be 0.5–3.7 kg/h (Wissink 1996), with an average kernel yield of 1.2–2.7 kg per 20 kg nuts. This is laborious, costly and can result in injuries. In the Solomon Islands higher rates of nut cracking have been reported (19–32 kg nuts per day), depending on shape, size of nut, shell thickness, skill and motivation of the crackers (Evans 1991b; 1994b). Even at the higher rates, nut cracking is a constraint to the expansion of commercial interest in *C. indicum* nuts and mechanical systems have been investigated but without much success, although in the Philippines an electric or hand driven mechanical cracker suitable for village based processing has been reported to crack nuts of *C. ovatum* at 112.5 kg/h, with an efficiency of 91% (www.dost.gov.ph/media/article.php?sid=292). Small-scale extraction of oil from *Canarium* kernels is done by mixing chopped kernels with water in the proportion of 1 kg kernels to 85 ml water (Evans 1994a). The oil is then squeezed from the slurry using a screw press.

Table 4 Grading schemes developed by Kandrian Gloucester Integrated Development Project and FPPU of Unitech Lae (1996) in Papua New Guinea (After: Srinivasan 1995; Wissink 1996)

	Grades	K:N ratio (FPPU)		K:N ratio (KGIDP)	
1	AA	>0.25		≥0.30	
2	A	0.18–0.25		0.20–0.29	
3	B	0.13–0.17		0.15–0.19	
4	C	<0.13	Rejected	0.10–0.14	
5	D	–	–	<0.10	Rejected

The Food Preservation and Processing Unit (FPPU) of the Papua New Guinea University of Technology (Unitech), Lae conducted a series of processing runs on *C. indicum* nuts between 1991 and 1995, using nuts from Morobe and Madang provinces. The results were encouraging, indicating that processing and marketing is viable and that there is good market potential for roasted nuts both locally and overseas (Srinivasan 1995). Shelling the nuts was found to be the most difficult and expensive part of processing. Food processing requires strict observation of food industry standards of hygiene (Evans 1994b) to avoid contamination. All rooms and equipment must be regularly cleaned, dried and kept free from rats, flies and dust. Oven drying at 60°C for 10 h is recommended to ensure desired quality for consumer acceptance and a long shelf life for *C. indicum* kernels (Evans 1994a). To enhance flavour, kernels can be salted or roasted. Trials at FPPU Unitech, with *C. indicum* showed that 5% salt added during blanching is sufficient for absorption by the kernel (Srinivasan 1993). The salt solution should be replaced frequently to prevent staining by tannins in the testa. The testa is the unpalatable 'skin' on the kernel that is removed before eating by squeezing the kernel between the thumb and the forefinger. The testa is excluded from commercial packets (Srinivasan 1994). It is difficult to remove testa when it is dry, and so needs to be rehydrated before removal (Evans 1991b/c). Soaking or blanching causes the

testa to expand and to peel away from the kernel easily. For roasting, remove the testa and spread salted kernels (1.5–2.0% moisture content) on stainless trays in a preheated oven at either 160°C for 15–20 min (Carlos and Dawes 1990), 130°C for 50–60 min (Maima 1996), or 120°C for 2 h (Evans 1994a). For vacuum packaging, kernels should be dried to at least 2.8% (Maima 1993). To prevent condensation in sealed packets, the roasted nuts should be air-cooled, as practiced commercially in Vanuatu. Vacuum packing holds the delicate kernels together and enhances their shelf-life, minimizing rancidity (Maima 1996; Evans 1994a). Use of clear plastic bags allows visual inspection of kernel quality and the retention of vacuum. For sale as snacks small 50 g packets, with an air-tight heat-sealing is recommended. Vacuum packing can obscure the kernels and make labelling difficult to read, however, this can be minimized by having a non-vacuum print area (Evans 1994a).

With the aim of increasing the income of people in the project area the Kandrian Gloucester Integrated Development Project (KGIDP) in West New Britain initiated a commercial enterprise focused on the production, processing, storage and marketing of *C. indicum* kernels and estimated that the potential production of the area was 1,500 tonnes per year (Wissink 1996). From 1993, it bought and processed nuts from the project area and sold them on local markets (Kandrian, Kimbe, Lae and Mt. Hagen) (Wissink 1996). However, despite a favourable financial model (Evans 1994a) which included substantial development and capital costs, the business closed in 1996 due to difficulties of meeting the market needs for quality, uniformity and regularity of supply.

Commercialization

A number of projects in Papua New Guinea, the Solomon Islands and Vanuatu have promoted the commercialization of *C. indicum* kernels and kernel oil, since the early 1990s. They have all focused on marketing kernels collected from the wild resource, including the naturally regenerating trees within farmland. However the approaches have been different. In Papua New Guinea, Development Projects assessed the costs of harvesting, extracting and processing the kernels, and made economic evaluations of the demand and supply (Stevens et al. 1996), including sending kernel samples overseas for evaluation in an attempt to identify potential overseas markets (Henderson 1996). During this period it was estimated that the formal market sold about 18 metric tonnes of kernels (packed into 50 g pack). This estimate does not take into account home consumption in rural areas, which is the main use of *C. indicum* nuts. These projects concluded that the indigenous nuts of the South Pacific, especially *C. indicum*, have great commercial potential (Bourke 1996). However, despite initial success in Papua New Guinea, the efforts of the FPPU of the Papua New Guinea University of Technology, Lae (Srinivasan 1993, 1994, 1995; Maima 1991, 1993, 1996), the Kandrian Gloucester Integrated Development Project (Mais 1997a; Wissink 1996) and the Pacific Heritage Foundation, failed to establish an industry. With regard to the marketing of whole kernels, a similar outcome has occurred in Solomon Islands, although through the Commodities Export Marketing Authority (CEMA) there has been a longer and more formalized commercial history in trading *C. indicum* kernels, going back to 1989. CEMA is responsible for internal trade, exporting and licensing (Pelomo et al. 1996) and the production of *C. indicum* nuts increased from 3 metric tonnes in 1989 to 45 and 2005 metric tones in 1991 and 1992 respectively, and included over 1,000 farmers (Evans 1994a). In 1993, purchases dropped to only 7,216 kg. Using 11 strategically located buying centres, CEMA bought nuts from growers and traders through its eight Copra Buying Centres and three agricultural stations, according to a grading scheme based on kernel:nut ratio (20% = 1st grade, 19–10% 2nd grade). During the period 1989–1993, CEMA bought 259 tonnes of *C. indicum* nuts, mainly from Malaita Province. Products promoted by CEMA included: edible kernels, kernel oil for cosmetic and pharmaceutical uses, and nut cake. Prices ranged from US$ 0.17 to US$ 0.34 per kilogram, depending on the grade, which was based on the kernel-to-nut ratio. Purchases

slowly increased as more villagers became aware of the scheme. Sales totalled US$100,427 with $37,592 from local sales and $62,835 from export. Throughout this period, some difficulties were experienced including the identification of means to establish reliable and appropriate quality control systems for both kernel and oil exports, and overcome high transport costs and the scale diseconomies encountered in marketing small product volumes (Fleming 1996).

In the Solomon Islands, *C. indicum* kernels were for a short time, successfully promoted overseas as a natural health food from the rainforest of South Pacific under the trade name ‘‘Solomon Nuts’’ (Evans 1991c). They targeted the national airline (Solomon Airways) and small packets were given out during flights to and from Honiara and were much appreciated. Health food shops were interested in the nutritional value of the nuts (Carlos and Dawes 1990; Harman and Anand 1990), but although the protein level is high, concerns were raised about level of saturated fat in the kernels. In 1992, the operational costs of this international marketing exercise, such as shipping, were subsidized through the Export Commodity Stabex fund of the Government of Solomon Islands, and *C. indicum* was beginning to be recognized as a new tropical nut on the world market (Carlos and Dawes 1990). However, as in Papua New Guinea, supply issues brought about the collapse of the trade. Nevertheless, the desire to promote *C. indicum* continues and is still alive in the Solomon Islands through the commercialization of kernel oil.

The approach in Vanuatu has been somewhat different. Instead of the commercialization activities being donor-funded Development Projects, a private entrepreneur (South Pacific Nuts) has developed a facility for drying, processing and packaging *C. indicum* and other indigenous nuts (*Terminalia catappa* and *Barringtonia procera*), This company has been successfully trading locally and with neighbouring countries since 1989. Currently, the company purchases air-dried nuts directly from villagers @ US$2,991 tonne (cracked and ready for processing). Nuts must be received by the South Pacific Nuts within 24 h of cracking or they are rejected. Suppliers normally crack nuts at their regional airfield prior to immediate transport to Port Vila. Nuts handled in this manner have a 90% acceptance level in Port Vila. If nuts are not processed within 24 h of cracking then post-harvest problems develop, leading to 50–60% loss of nuts after 48 h. The company has used a specially designed mechanical nut cracker to reduce the labour intensive cracking process (Wah 1996). The machine has a typical production ratio of 35% undamaged to 65% damaged kernels, compared to a 90% undamaged to 10% damaged ratio when cracking is done by hand. The ‘Mechanical Cracker’ is best suited to a high, volume, plantation type situation, where high volumes of product were being produced of alternative product forms where kernel damage was not a major issue (for example, if producing flakes). However, current practice is for South Pacific Nuts to sell the nuts to local people (often women working from home) for US$7.48 per 25 kg bag and then buys back the kernels for US$2.99 per kg. A 25 kg bag of nuts will typically yield about 5 kg of kernels. An experienced cracker can crack up to 75 kg per day and so can earn about US$22.44 per day.

Currently, nuts are sourced from Tanna, Santo, Maewo and Malekula each year and transported to Port Vila. The nuts are then further dried and stored in vacuum-packed bags and modified atmosphere jars for storage and export. Organic certification has been well received by the market. The consequence of these developments is that business is constrained by supply, which fluctuates annually. The company has therefore been promoting tree planting through radio messages and leaflets. These issues are demonstrated by the year-to-year fluctuations in the sales of kernels by South Pacific Nuts (Table 5).

Vanuatu has also exporting dried *C. indicum* kernels to France, Japan and New Caledonia (McGregor 1999). In 2002, 300 tonnes were exported by the South Pacific Nuts (in shell) in 2002 to Australia, Japan and Hawaii. However exports have virtually ceased since because demand is exceeding supply on the domestic market as a result of promotional and marketing activities (Emmett 2004). In 2004, South Pacific Nuts purchased 180 tonnes *Canarium* (nut in shell) resulting in 18 tonnes kernels. This product was predominantly marketed in 100 g plastic packets

Table 5 Sales of *C. indicum* (kg) kernels by the South Pacific Nuts, Santo, Vanuatu (McGregor 1999)

	1993	1994	1995	1996	1997	1998	1999 (to October)	2000 (expected)
C. indicum kernels	100	1,700	400	1,200	800	280	2,600	10,000

sold exclusively within Port Vila to shops, hotels and restaurants at Vatu 200 (200 Vatu = US $1.79 cents). This represented a market return of Vatu 2,000,000 (US$18,204) per tonne of nuts.

Other international marketing initiatives have included sending kernel samples overseas from the Solomon Islands for consumer trials and market assessment (Srinivasan 1994; Henderson 1996). For example, samples were sent to 25 manufacturers and nut packers/distributors in USA and Canada for consumer tasting trials (Eulensen 1994). Seventeen companies responded and two of these (Del Rey Nut Company and Melissa's World Variety) demonstrated strong interest, while five others (The Wild Side, Ben & Jerry's Homemade Ice Cream, Cloud Nine Chocolates, Ethel M Fine Chocolates and New England Natural Bakers) expressed interest, but were unsure of the long-term market potential. The interested respondents were mostly gourmet/specialty food companies. Among the other responses, 10 companies indicated that they considered the taste too bland for American consumers. Other concerns were about the high saturated fat content of *C. indicum* (34%) relative to other nuts already in the marketplace (5–11% for macadamia, pecan, pine and pistachio). A microbiological analysis of the nuts returned acceptable results, although the *E. coli* count was too high for use in dairy products. Subsequent to this study, two other US companies, which heard about *C. indicum* nuts at the New York City Fancy Foods show, expressed interest in receiving samples. Similar market studies have been conducted in Australia (Davidson and Thomson 1997, 1998).

The marketing of kernel oil has been more successful in the Solomon Islands than the marketing of whole kernels. Again, although starting as a Development Project, it has more recently involved a private company. The kernel oil project started in 1992 as a model community conservation project in which kernel oil was developed as an alternative source of income, at a time when Malaysian loggers were active in central Bauro. The conservation focus has involved Conservation International, International Council for Bird Preservation, Biodiversity Conservation Network (WWF, The Nature Conservancy and World Resources Institute) with funding from USAID and MacArthur Foundation (London 1996). The project started with a study of the commercial feasibility targeting domestic and international markets. Domestically the oil is used for cooking and has local markets. The project was relatively successful and through this initiative communities were trained in grading and oil extraction. In 1995, a socio-economic survey had identified a number of issues affecting the impact of harvesting and marketing kernel oil, and community structures to resolve any problems. Women in particular benefited from the project allowing them to buy household utensils and to pay for clothing and school fees. Other benefits from the project were a health clinic and two-way radio with Kirakira hospital. The inclusion of international trading in oil, rather than kernels was the outcome of a study based on eight criteria to determine the commercial viability of a *C. indicum* enterprise (London 1996). Unfortunately, the international marketing initiatives have suffered from quality issues, which have restricted expansion. Market research by Conservation International created markets in USA (200 l exported to the Body Shop in UK and another 200 l to USACorda in 1993). These exports were expedited with the services of Commodity Export and Marketing Authority (CEMA). This oil was used in tanning lotion, but after a short time quality issues arose which closed this link with the Body Shop (Pelomo et al. 1996). Since 1996, the primary market for the kernel oil from the Solomon Islands has been an Australian-based pharmacy, 'The Apothecary'. Kernel oil is used by the Apothecary as the active ingredient in a patented ointment designed to relieve arthritis. This product, marketed as 'Arthrileaf' is a pharmaceutical formulation composed of 5% *Canarium* nut oil and 95% sorbolene (McGown 2003), which is sold on the internet for US$30 for a 50 g jar (www.get-arthritis-relief-now.com), but can be

obtained in Australia for about US$12 wholesale. Lower grade kernel oil has also been purchased in smaller volumes by a New Zealand based company for use in soap.

The way forwards

In Papua New Guinea and the Solomon Islands, the collapse of marketing activity for whole *Canarium* kernels appears to be due to supply issues, and that quality control throughout the supply chain was the biggest of these. Regularity of supply was also an issue. Together these supply issues have greatly hindered the development of the indigenous nut industry (McGregor 1999). Many studies have shown that the potential market is large, but supplying this market is hampered by loss of quality arising from village level processing. A consequence of this is the failure to meet food quality controls in formal markets. Improving on-farm processing and storage of kernels is therefore one important component to overcoming supply issues. Another issue is the variability in product quality arising from wild harvesting from undomesticated trees, and again the need to meet quality standards. Wild harvesting also creates significant problems regarding variation in the availability of kernels and the reliability of supply. These problems can be addressed by the creation of planted areas with selected cultivars grown under agroforestry or plantations.

However, it is also clear that for commercialization, private sector initiatives work better than the establishment of development projects, as in the case of the commercial company in Vanuatu (McGregor 1999). Thus the future of the processing and marketing of *C. indicum* and other nuts in the Pacific is very dependent on local business entrepreneurs and Government support. To develop functioning markets it is essential that the marketing chain includes: market information, reliable production, effective transport to markets, product promotion, and fair pricing at the farm gate/the middle man and in the major markets and shops, and effective and attractive packaging. However, success is also dependent on the quantity, quality and consistency of supply from the producers, which is difficult when the products are harvested from species, which are not highly domesticated. In conclusion, through the integration of domestication and commercialization if should be possible to take advantages of the genetic variability in shape, taste, colour, texture, nutrient content, seasonality, etc., and the post-harvest techniques of drying, cleaning and storing the kernels.

Two other matters are of considerable importance for the development of a sustainable industry in the future. The first of these is the conservation of genetic resources. *Canarium* species are among a number of indigenous fruit and nut trees in a programme of genetic resources conservation under the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) (Evans 1999; Sam et al. 2002). In addition, a conservation plan for Vanuatu and Solomon Islands has been prepared by Department of Forests (Vanuatu), Forestry Division (Solomon Islands), SPRIG and Secretariat of the Pacific Community (SPC) Forests and Trees Program (Sam et al. 2002) to ensure the in situ and ex situ conservation of genetically and economically important nut morphotypes for future research and development. A gene conservation stand of superior nut morphotypes was planted at Shark Bay, Santo in Vanuatu in 1999 (Thomson and Evans 2001a).

The second important matter is the protection of Intellectual Property Rights (IPR) at the community level. Issues about IPR associated with *C. indicum* have been raised since patents have been granted in USA, South Africa, Japan and Australia for medicinal use of *Canarium* nut oil, sourced from the Solomon Islands. Particular concern has been raised in the Solomon Islands that this patent for use of the oil for therapy for arthritis and associated conditions has not recognized the traditional knowledge of the people. These matters were discussed at a Workshop in Honiara in August 2004 to determine the issues of ownership, IPR, and strategies for preventing similar problems in the future (Biliki 2004; Davis 2004; Sanderson and Sherman 2004).

Currently, there is renewed interest across Melanesia in developing indigenous nuts, especially *C. indicum*, as marketable products. In the Solomon

Islands, through the kernel oil project, there is continuing interest in developing markets for *C. indicum* nuts. This still has a strong focus on the Project in Central Bauro, Marika Province. The Warihito community live along 20 km of the coast and consists of 9 villages (Suguasi, Warihinou, Haurari, Manasugu, Goge, Bagoasi, Namopugo, Nagonatara and Nagogona), with a population of more than 5,000 people (Wale 2004). AusAID (2004) has reported that the potential commercial urban retail market for simply packaged *Canarium* nuts in Solomon Islands has been conservatively estimated to be worth US$187,000 per year (5,000 kg of kernels at $50 per kg) and US$49,360 at the farm gate (33 tonnes of nut-in-shell at $1496 per tonne). In parallel with this, some plantation owners in Papua New Guinea are processing and selling nuts in hotels, clubs, supermarkets and expatriate communities in Rabaul and Kokopo. It seems that opportunities to market packaged *C. indicum* kernels in domestic markets is growing as a result of an increasing urban population and demands for better foods. In addition, a study by the Horticulture Industry Sector Study (McGregor et al. 2003) commissioned by the Papua New Guinea Department of Agriculture and Livestock as part of the Government's Export Driven Economic Recovery and Development Strategy, has reported that:

- Tree nuts probably offer the best export market prospects of any horticultural product from Papua New Guinea.
- Perhaps the biggest constraint to expanding formal market sales is the lack of consistency in supply, in terms of quality and volume.
- Significant expansion of the commercial horticultural industry requires greater specialization by farmers in growing and not marketing.
- Supermarkets and other institutions now represent a major market for fresh produce with scope for significantly increased sale of local produce.

Consequently, a new project in Papua New Guinea at the National Agricultural Research Institute's Lowlands Agriculture Experimental Station in Keravat, is in progress. This time attention is initially being focused on the supply issues, which caused the failure of the earlier projects which focused mainly on marketing. Thus the current project is combining efforts to improve marketing of indigenous nuts across Melanesia (Papua New Guinea, Solomon Islands and Vanuatu), through an integrated region-wide supply chain with the development of selected superior cultivars for large-scale agroforestry plantings that will improve the regularity of supply, the uniformity of the marketable products meeting a number of different commercial opportunities. The domestication activities will be done with a number of pilot communities through a participatory approach (Leakey et al. 2003; Tchoundjeu et al. 2006), that has been successful in West Africa.

Conclusion

This review highlights that *C. indicum* produces marketable products with great potential to improve the livelihoods of rural households in Papua New Guinea, the Solomon Islands and Vanuatu. AusAID (2004) has estimated that the value of the combined *C. indicum* markets of the Solomon Islands, Papua New Guinea and Vanuatu is US$0.75 million per year (20,000 kg of kernels), of which $0.19 million per annum is the value at the farm gate. However, for wider marketing to be successful their needs to be greater attention paid to resolving the supply issues that have to date hindered market development. These issues are the reliability of supply and the quality and uniformity of the products.

To ensure the supply of high quality *C. indicum* kernels it is necessary, firstly, to increase the size and quality of the available resource by promoting planting in homegardens and integration in agroforestry systems with cocoa and other cash crops, to provide shade and a wider range of products. The quality and uniformity of the products can be improved through domestication of the species as a crop so that these plantings can increasingly be made with selected cultivars, such as has occurred with indigenous fruits and nuts elsewhere in the tropics (Leakey et al. 2005). Because of the interest of households in the rural community, there is great potential in Papua New Guinea for this domestication programme to

follow the procedures of participatory domestication developed in Africa (Leakey et al. 2003; Tchoundjeu et al. 2006). In this case, farmers would be taught how to propagate the elite trees in their villages using simple vegetative propagation techniques (Leakey et al. 1990), so producing cultivars with large, easily-extracted kernels with desirable nutritional and perhaps medicinal qualities, across a wide production season, according to various market-driven ideotypes (Leakey and Page 2006).

Second, this review has highlighted the need for *C. indicum* market development in Melanesia. Initially market development should focus on satisfying local and regional demand. This requires the development of a more effective supply chain across Melanesia (Bunt and Leakey, submitted) and improved quality of processing and packaging to enhance shelf-life, retain natural flavour and sensory characteristics, and meet the hygiene requirements of overseas markets. Then market expansion can follow as the supply grows and the non-traditional consumers become more familiar with the products. To achieve the above there is also a need to provide information to growers, potential entrepreneurs, governments, institutions and consumers, who all need to be educated about this new crop.

The issues highlighted in this review were part of a feasibility study to examine the options for developing *C. indicum* as an agroforestry crop for poverty alleviation in Papua New Guinea in ways that build on the past experience. This study initiated producer and consumer surveys (Nevenimo et al., submitted) and has in particular examined the opportunities to integrate domestication with commercialization. It also undertook a preliminary characterization and evaluation of tree-to-tree variation (Leakey et al., submitted), and a marketing analysis (Bunt and Leakey, submitted). Now a new research and development project has been funded at the National Agricultural Research Institute of Papua New Guinea's Lowlands Agriculture Experimental Station in Keravat, East New Britain, to facilitate the parallel implementation of the above domestication and commercialization activities. This new project is combining efforts to develop selected superior cultivars for large-scale agroforestry plantings through village-level domestication, with meeting a number of different commercial opportunities across Melanesia (Papua New Guinea, Solomon Islands and Vanuatu), through an integrated region-wide supply chain. This approach is expected to enhance kernel quality and the surety of supply and so to develop market confidence. In this way this new project seeks to develop a model, which will be applicable to many other AFTPs facing similar domestication and commercialization challenges.

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